Architecture of a Multiscale Aerosol Climate Model

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Why a Multiscale Model?

- Uncertainty in estimates of direct and indirect effects by anthropogenic aerosols is comparable to the forcing by anthropogenic greenhouse gases
- Direct effects are a highly nonlinear function of RH
- Indirect effects are a nonlinear function of
  - Updraft velocity
  - Aerosol concentration
  - Cloud thickness
- Aerosol concentrations are strongly affected by clouds and precipitation
  - Convective cloud vertical transport
  - Cloud chemistry
  - Precipitation scavenging

All poorly resolved or parameterized in GCMs

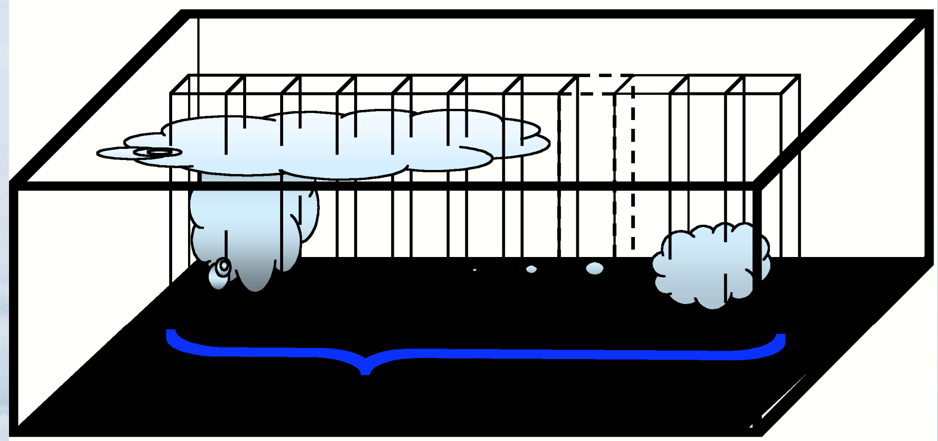
Convective Clouds are Problematic

- Cumulus parameterizations rely on a wide variety of closure assumptions.
- The vertical flux of mass diagnosed by cumulus parameterizations is sensitive to the closure assumption.
- Vertical transport of aerosol and precursor gases is sensitive to cumulus parameterization.
- None of the cumulus parameterizations estimate cloud or precipitation volume.
- Representation of cloud microphysics in cumulus parameterizations is extremely crude.
- Aerosol effects on cumulus clouds are neglected in all global models.

One Solution

- The Cloud Resolving Models embedded within the Multiscale Modeling Framework provide a powerful framework for translating improved process understanding into improved global-scale models.
- Embedding pollutant transport, transformation, and removal within the CRMs in each global model grid cell would provide a much more reliable physically-based subgrid treatment of cloud processing of pollutants and of direct and indirect effects of aerosols.

A Global Climate Model column

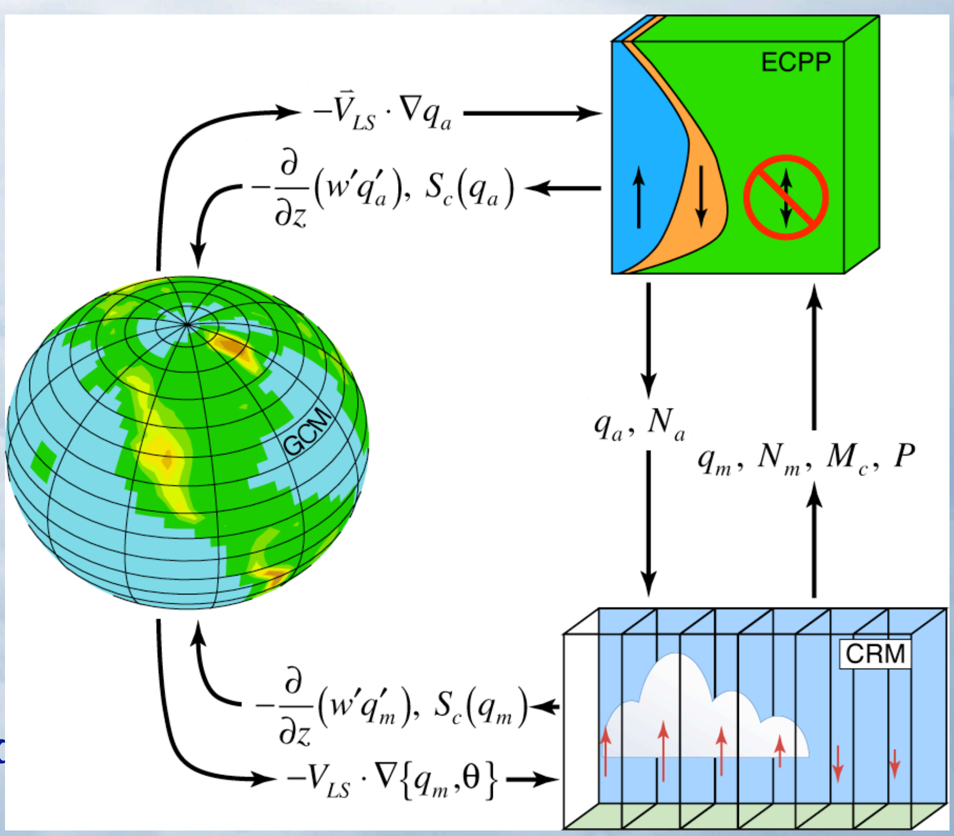


But Too Time-Consuming

- The MMF currently runs about 200 times slower than climate models with conventional cloud parameterizations.
- Plans for future MMF simulations will cost even more:
  - Six-fold for Δx=1 km instead of 4 km
  - Three-fold for quasi-3D on geodesic grid
  - Hundred-fold for full 3D
- Chemistry and aerosol physics can cost 2-10 times as much as typical climate physics.
- Adding chemistry and aerosol physics to embedded CRMs would produce a computational monster.

An Alternative:
Explicit Clouds - Parameterized Pollutants

- Use grid cell mean statistics from the CRM simulation to drive a physically-based treatment of pollutant processing by clouds and of direct and indirect effects
  - use mean cloud mass flux to treat vertical transport of pollutants
  - use mean updraft velocity to determine the aerosol activation and droplet nucleation
  - use mean cloud fraction and in-cloud water content to treat aqueous chemistry
  - use mean precipitation fraction and precipitation rate to treat precipitation scavenging
  - use CRM RH to calculate water uptake and direct effects
  - use CRM droplet number and cloud water for indirect effects.



Explicit Clouds – Parameterized Pollutants

Diagnose mean upward and downward cloud mass flux

$\overline{M}_{up} = \int_{\sigma_c} \rho w d\sigma_c$ if $w>0$ and $q_c > 0.01q^*$ $\overline{M}_{dn} = \int_{\sigma_p} \rho w d\sigma_p$ if $w<0$ and $q_p > 0.1$ g/kg

Diagnose entrainment and detrainment rates from the cloud mass flux

$$\frac{\partial \overline{M}_{up}}{\partial z} = \overline{M}_{up}\left(\varepsilon_{up} - \delta_{up}\right) \qquad \frac{\partial \overline{M}_{dn}}{\partial z} = \overline{M}_{dn}\left(\varepsilon_{dn} - \delta_{dn}\right)$$

by assuming the cloud updrafts entrain air only if the upward mass flux increases with altitude and detrain air only if the mass flux decreases with altitude, and downdrafts entrain only if the downward mass flux increases downward and detrain only if the mass flux decreases downward.

Diagnose pollutant concentrations in updrafts and downdrafts by integrating conservation equations

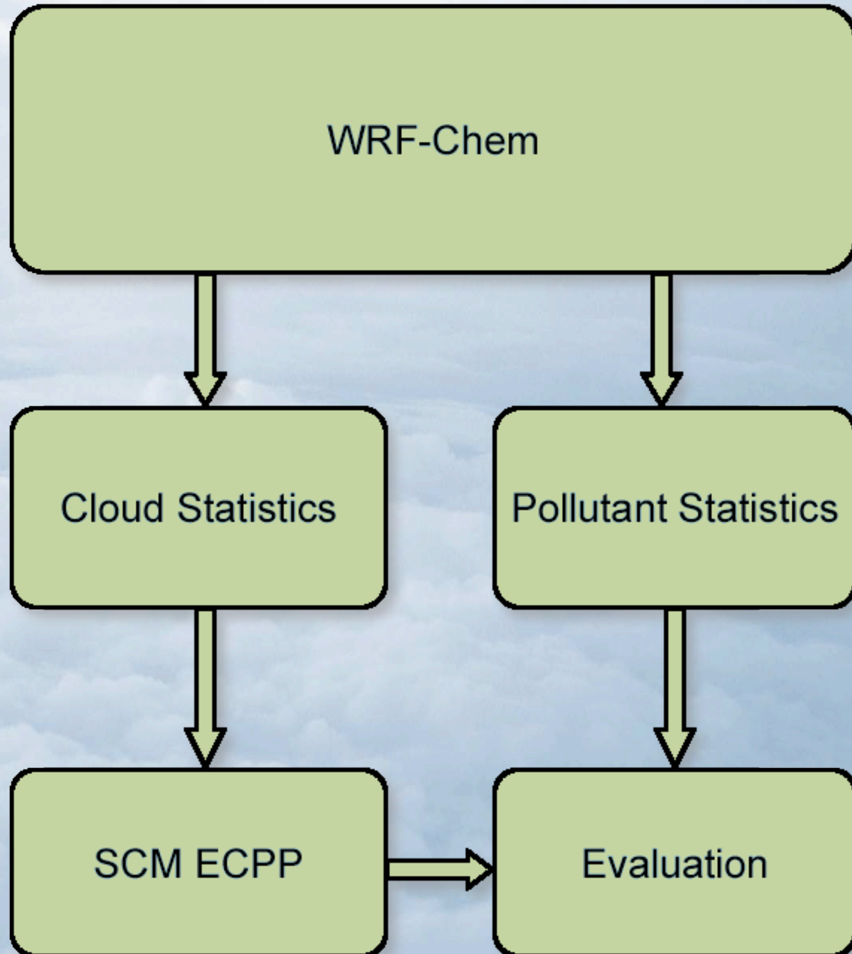
$$\frac{\partial \overline{M}_{up} C_{c,up}}{\partial z} = \overline{M}_{up}\left(\varepsilon_{up}\overline{C} - \delta_{up} C_{c,up}\right) + \overline{S}_{c,up} \qquad \frac{\partial \overline{M}_{dn} C_{c,dn}}{\partial z} = \overline{M}_{dn}\left(\varepsilon_{dn}\overline{C} - \delta_{dn} C_{c,dn}\right) + \overline{S}_{c,dn}$$

Cumulus transport can then be expressed

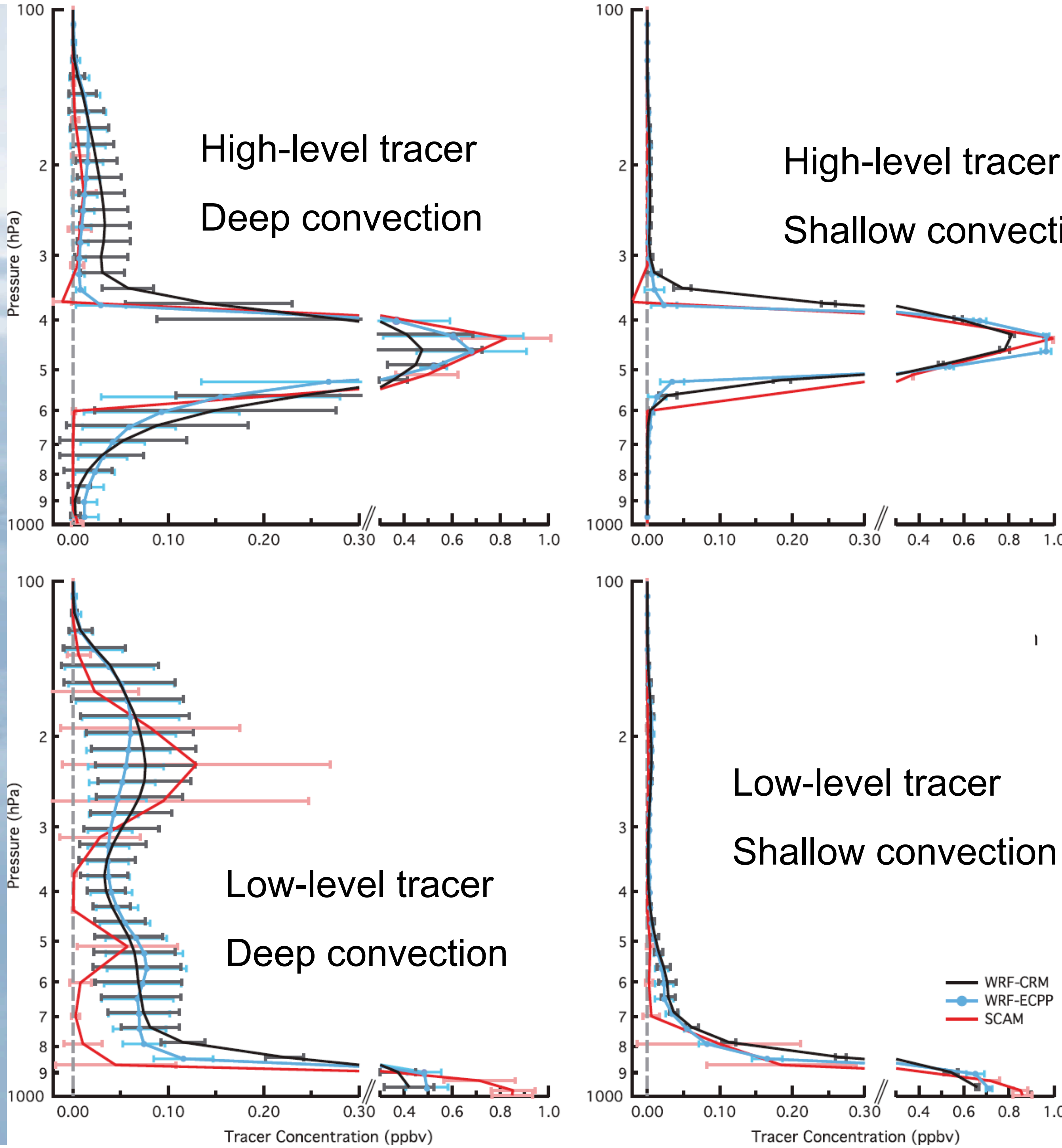
$$\overline{\rho}\,\overline{w'C'} = \overline{M}_{up}\left(C_{c,up} - \overline{C}\right) + \overline{M}_{dn}\left(C_{c,dn} - \overline{C}\right)$$

Testing the ECPP Concept

- Perform cloud-resolving pollution simulations with WRF-Chem
- From model history calculate domain averaged cloud statistics
- Use cloud statistics to drive SCM with ECPP
- Evaluate SCM pollutant simulation using domain averaged pollutant statistics from WRF-Chem simulation

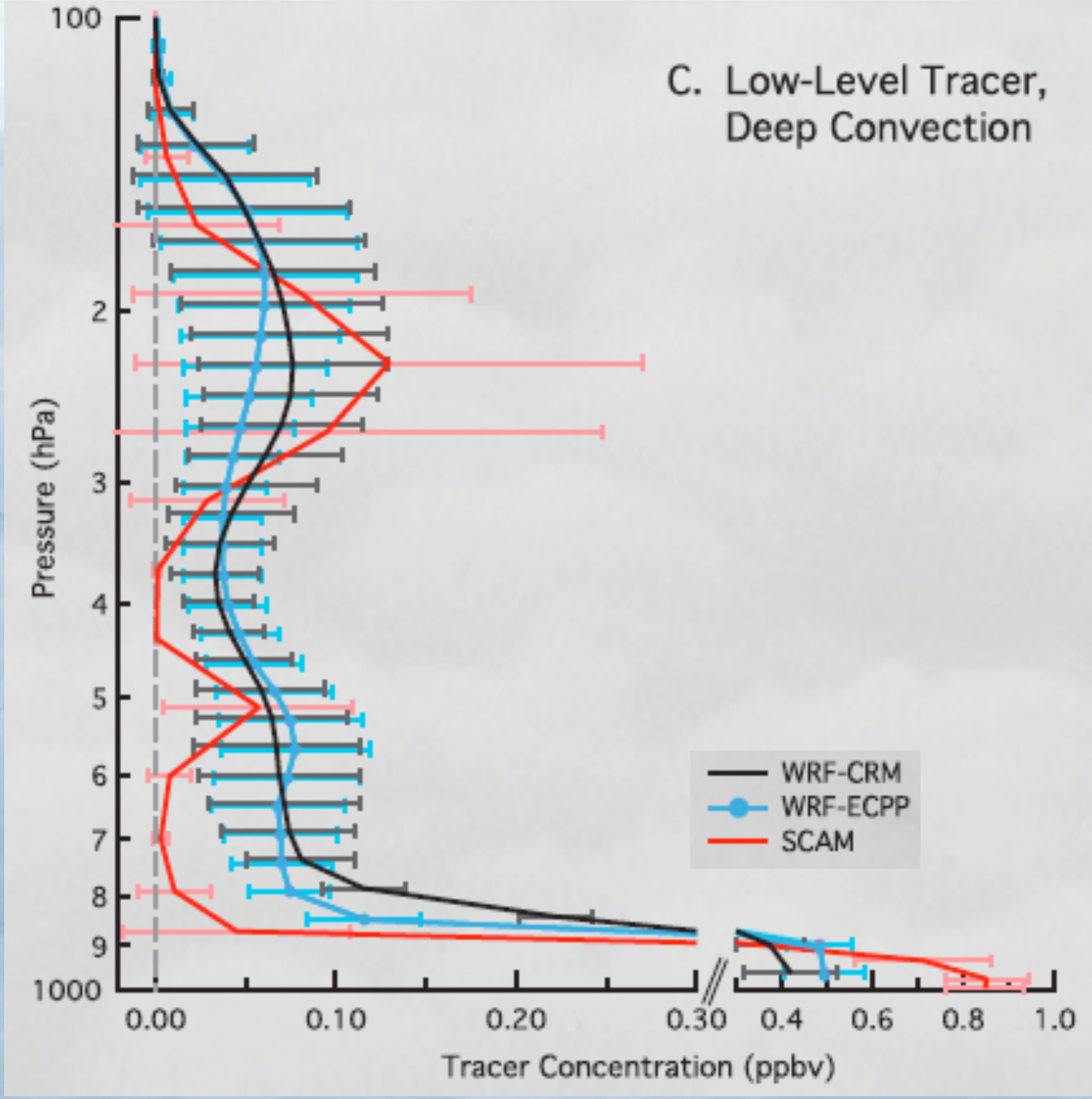


Testing Transport Only

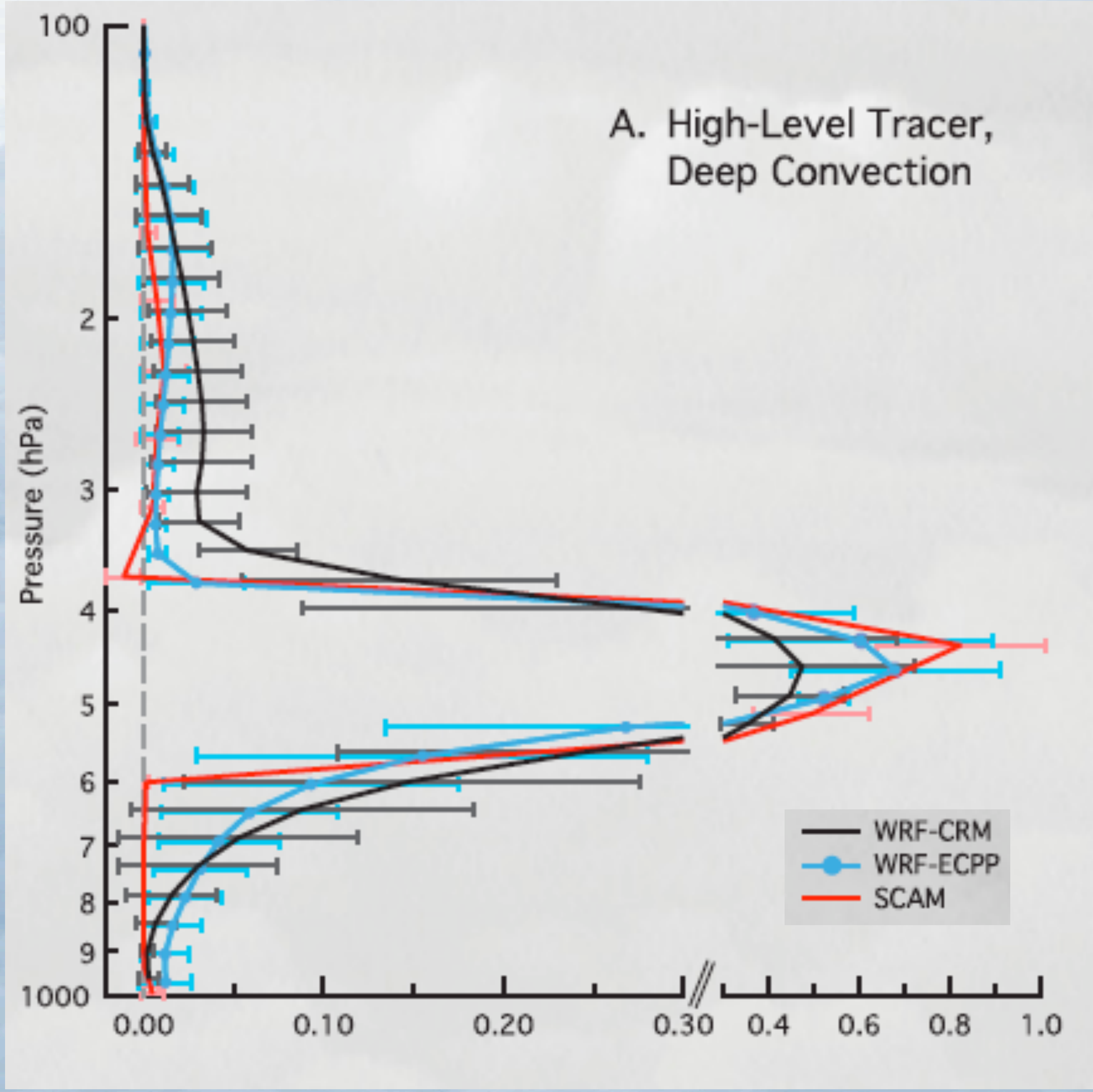


Benchmark
ECPP
Parameterized convection

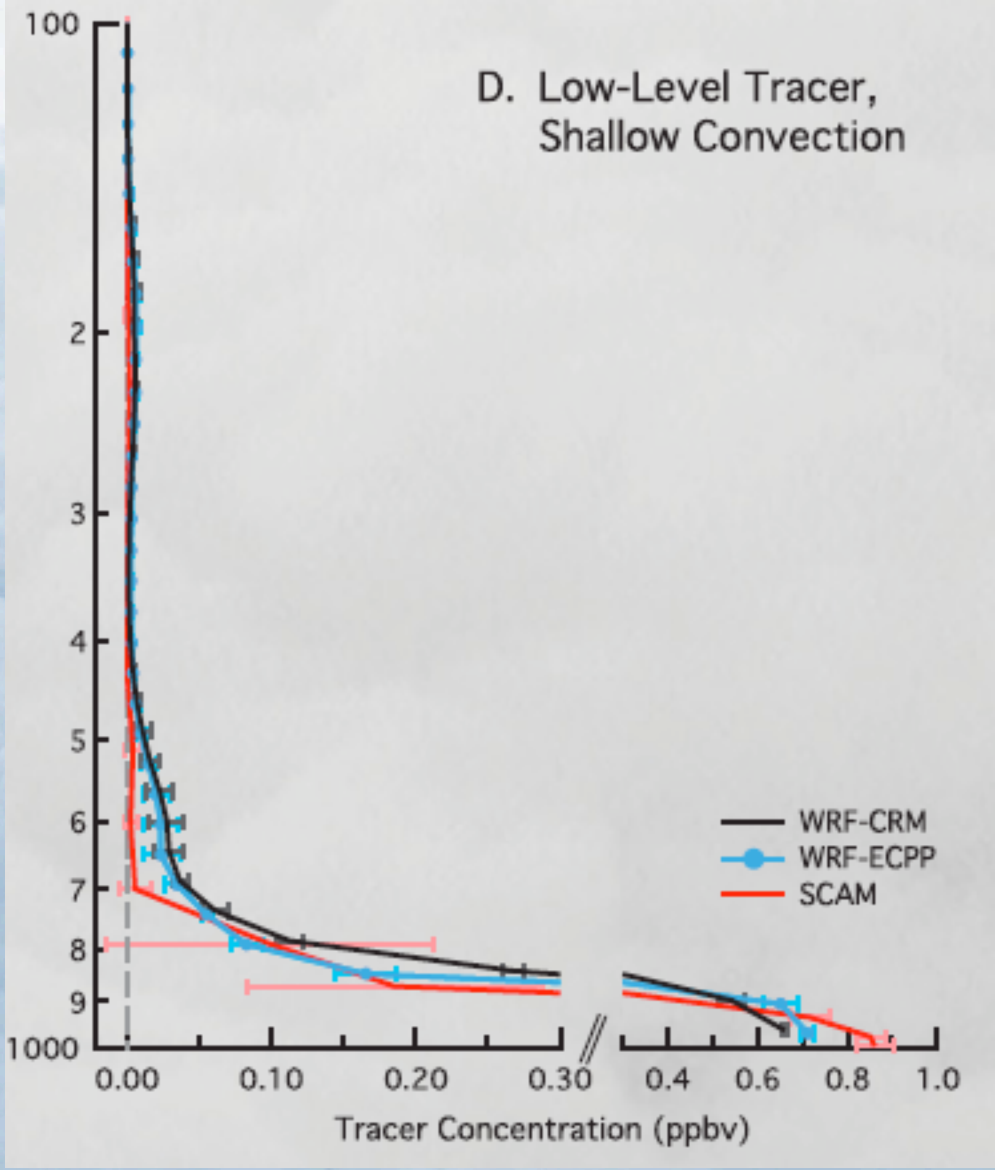
Testing Transport Only



Transport of a High-level Tracer



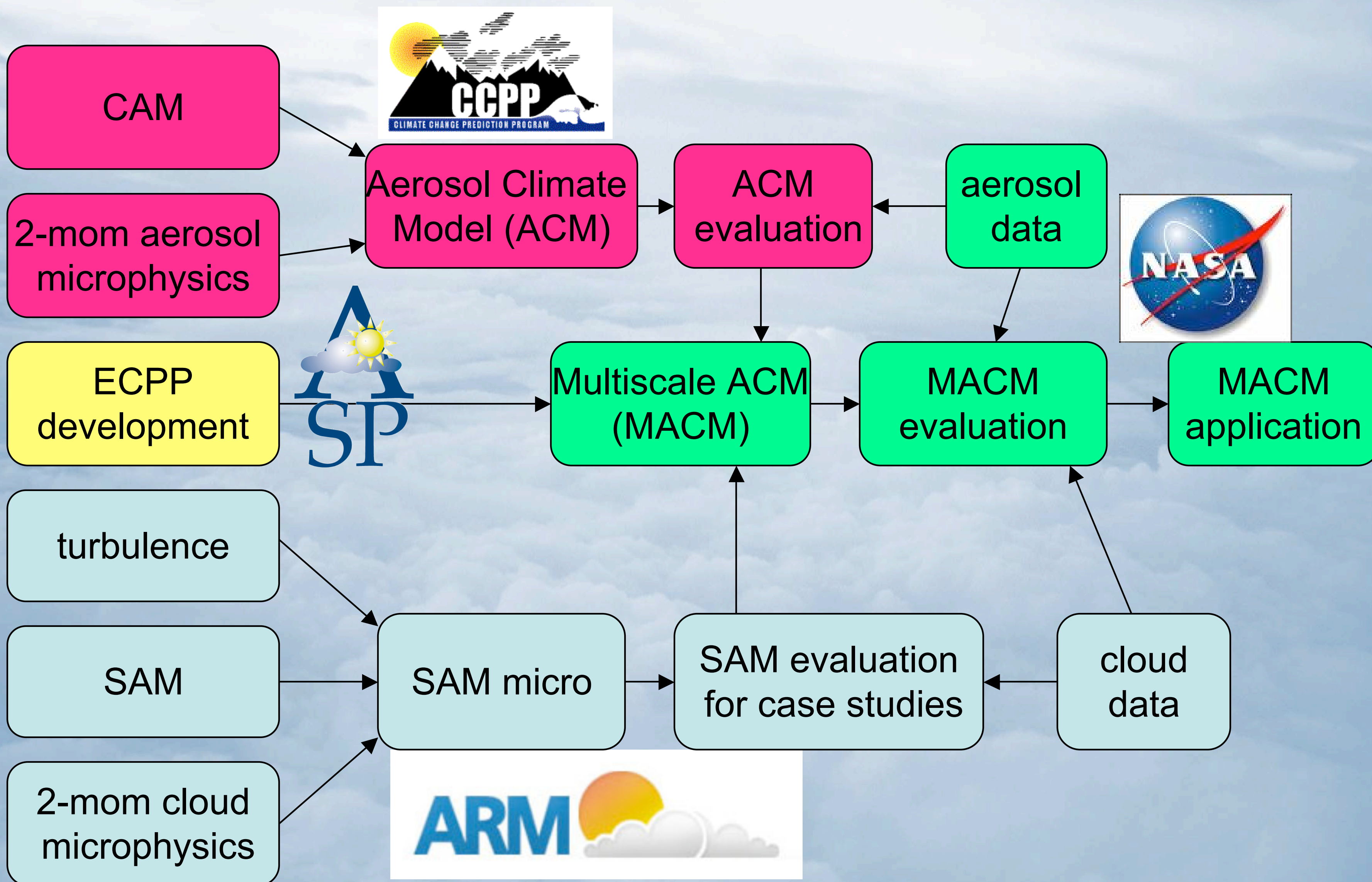
Transport by Shallow Convection



Building Blocks for the Multiscale Model

- Community Atmosphere Model (CAM)
- modal 2-moment aerosol physics
- System for Atmospheric Modeling (SAM)
- Vaughan Phillips 2-moment cloud microphysics
- Golaz and Larson higher-order turbulence closure
- Latin hypercube sampling of cloud microphysics
- Explicit Clouds Parameterized Pollutants (ECPP)
- ECMWF reanalysis
- A-Train satellite data
- Surface-based aerosol remote sensing
- In situ cloud and aerosol measurements

Roadmap


CCPP
CLIMATE CHANGE PREDICTION PROGRAM
CAM
Aerosol Climate Model (ACM)
ACM evaluation
aerosol data
2-mom aerosol microphysics
NASA
ECPP development
ASP
Multiscale ACM (MACM)
MACM evaluation
MACM application
turbulence
SAM
SAM micro
SAM evaluation for case studies
cloud data
2-mom cloud microphysics
ARM


Questions?